ADVANCES IN CHIMERA GRID TOOLS FOR MULTI-BODY DYNAMICS SIMULATIONS AND SCRIPT CREATION

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OVERVIEW

> Framework for multi-body dynamics - Geometry Manipulation Protocol (GMP)

> Dynamics simulation using Chimera Grid Tools (CGT) and OVERFLOW-2

> Further recent developments in Chimera Grid Tools
- OVERGRID
- Grid modules
- Script library

> Summary and future work

MULTIPLE COMPONENT DYNAMICS

Motivation - Problem setup is difficult and not standardized

Objective - Develop solver-independent standard protocol
Make it easy to use

Approach
- Develop protocols and tools for describing
  - hierarchical relationship between static/moving components, grids, geometry, etc.
  - prescribed motion
  - 6-dof motion with external loads and constraints

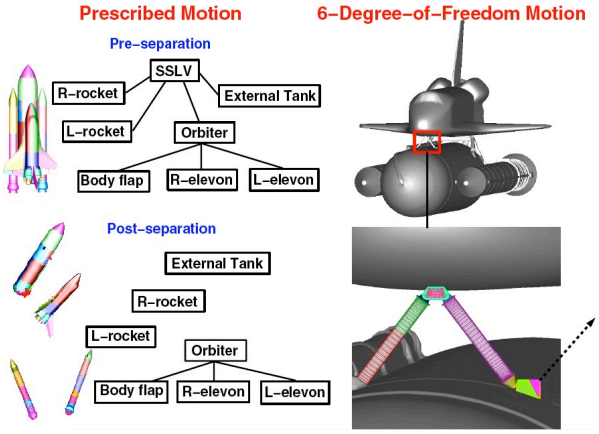
Murman, S. M., Chan, W. M., Aftosmis, M. J., Meakin, R. L., `An Interface for Specifying Rigid-Body Motions for CFD Applications', AIAA Paper 2003-1237, 41st AIAA Aerospace Sciences Meeting, Jan., 2003

GEOMETRY MANIPULATION PROTOCOL

Configuration
Each component may
- have one immediate parent or no parent
- move relative to the parent
- be linked to geometry or grids (structured/unstructured)
- have an initial transform (rotate/translate/mirror)

Scenario
Motion of each component may be
- **Prescribed** - sequence of rotate and translate commands that are analytic functions of time
- **Aero6dof** - specified by
  - mass properties (mass, principal moments of inertia, and principal axes orientation)
  - initial location of center of mass
  - external loads and constraints (gravity,app. load, etc.)

EXAMPLES OF PRESCRIBED AND 6-DOF MOTION



MULTI-BODY CFD SIMULATIONS (previous procedure)

> Write special code for dynamics of each component

> Determine how to interface with flow solver by
- reading complicated documentation (if any)
- talking to flow solver authors (if available)

> Recompile flow solver

> Verify and debug by running flow solver

> Plot grids at different times to check dynamics

MULTI-BODY CFD SIMULATIONS (current procedure)

Pre-processing using OVERGRID

> Define components (hierarchy/grid links)
> Specify and verify dynamics before running flow solver
- animate prescribed motion
- animate 6-dof motion by solving Newton's and Euler's equations of motion (zero aero loads assumed)

> Write XML files for flow solver to read

Solution computation using OVERFLOW-2

> Read XML files from OVERGRID for dynamics input
> No code writing, recompilation or knowledge of flow solver interface needed

Post-processing using OVERGRID and OVERPLOT

> Animate 6-dof motion of components
> Animate scalar quantities with simple solution viewer
> Plot component force/moment breakdown, residuals,etc.

CURRENT VALIDATED CAPABILITIES IN OVERFLOW-2

> Each component undergoes either prescribed or 6-dof motion for all time

> Some components may have prescribed motion followed by 6-dof motion

> Applied forces and moments for 6-dof motion are allowed to be functions of time

> Simple constrained 6-dof motion is coded but not validated yet

VALIDATION TEST CASES FOR GMP DYNAMICS

Comparison with analytic solutions (aero-loads turned off)

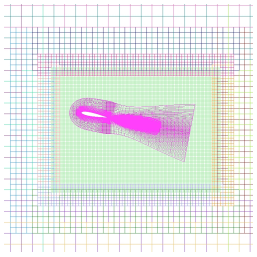
> Sphere dropped under gravity
- initially at rest, with time varying resistive force
- with initial upward velocity

> Tumbling cylinder pinned at center of mass (no gravity)
- with initial angular velocity

Comparison with experiments

> Oscillating airfoil
- prescribed motion, dual time step

-0.2 <= alpha <= 8.2 (case 1)
6.8 <= alpha <= 15.2 (case 2)
10.8 <= alpha <= 19.2 (case 3)

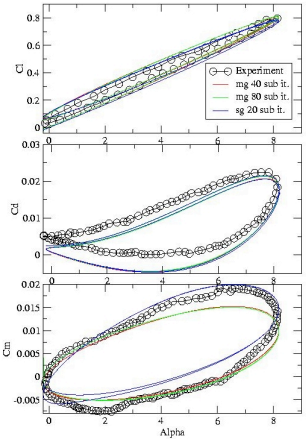


OSCILLATING AIRFOIL TEST CASE 1
-0.2 <= alpha <= 8.2, DTPHYS=0.157, 200 steps/cycle

Lift

Drag

Pitching moment

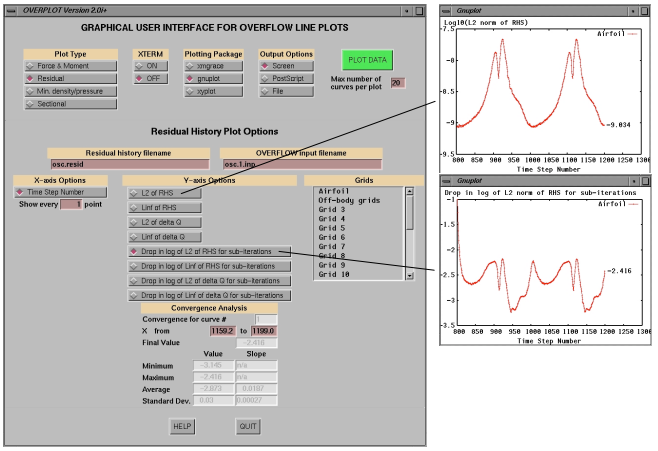


Multiple-grid
- 40 sub-iterations
- 80 sub-iterations

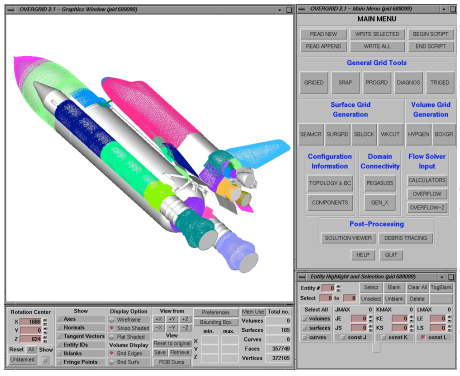
Single-grid
- 20 sub-iterations

Reference
Ko, S. and McCroskey, W. J., Computations of Unsteady Separating Flows over an Oscillating Airfoil, AIAA Paper 95-0312, 1995.

OVERPLOT POST-PROCESSING INTERFACE
RESIDUALS PANEL



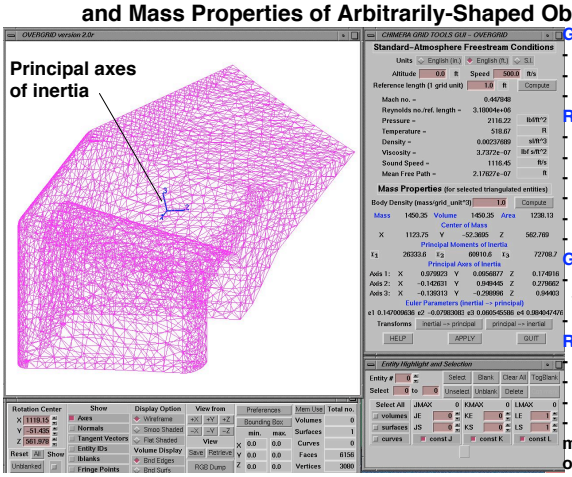
OVERGRID GRAPHICAL USER INTERFACE



Capabilities
- Geometry processing (structured panels, triangulations)
- Grid processing, redistribution, projection
- Surface and volume grid generation (TFI, hyperbolic)
- Grid diagnostics
- Flow solver inputs and boundary conditions preparation
- Multiple components dynamics input and animation
- Atmospheric conditions and mass properties calculators
- Simple solution viewer
- Debris trajectory analysis

Supported platforms - Unix, Linux, Mac OS-X

Calculators for Standard Atmosphere Freestream Properties and Mass Properties of Arbitrarily-Shaped Objects



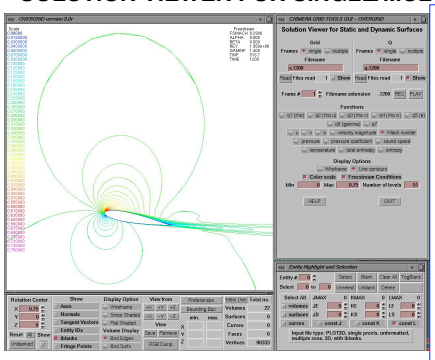
Given:
- altitude
- speed
- ref. length

Return:
- Mach no.
- Reynolds no.
- temperature
- density
- viscosity
- sound speed

Given:
- surface-triangulation density

Return:
- mass, volume
- surface area
- c. of mass
- principal moments/axes of inertia

SOLUTION VIEWER FOR SINGLE/MULTIPLE TIME FRAMES



Need a fast way to look at dynamic solutions

Auto-loading of all L=1 surfaces

4 clicks to animation with auto file ext. detection
- select multiple frames
- read grid frames
- read q frames
- play or record

Usual scalar functions & all q variables (species, turbulence model vars.)
- Color contours
- Grid wireframes

Grid frame	Q frame	Solutions
Single	Single	3-D steady state
Single	Multiple	3-D time accurate or non-time accurate
Multiple	Multiple	3-D time accurate moving bodies, 2-D dynamic adaptive grids

DEBRIS TRAJECTORY ANALYSIS INTERFACE

OVERGRID/DPREP → **DEBRIS** → **DPROX**

GUI/script input preparation | Trajectory computation | Proximity detection

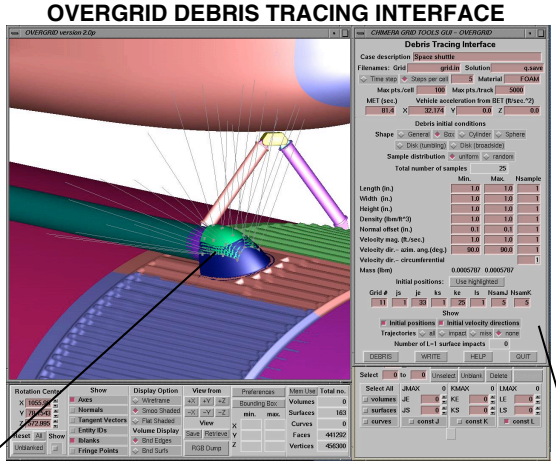
> Specify
- uniform or random sample distribution
- shape (general / box / cylinder / sphere / tumbling disk / broadside disk / frustum / micro-sphere/cylinder)
- attribute range(min and max) for density, length/width/height/diameter, normal offset distance, velocity magnitude and direction (elevation, azimuthal)

> Specify and view initial debris positions, velocity vectors

> Auto-generate input file for DEBRIS code

> Option to execute DEBRIS code and view trajectories, impact points colored by impact speed

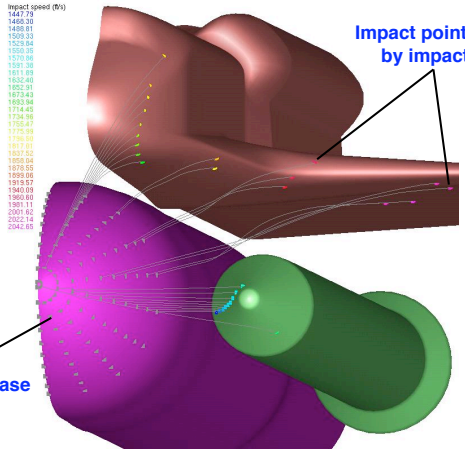
OVERGRID DEBRIS TRACING INTERFACE



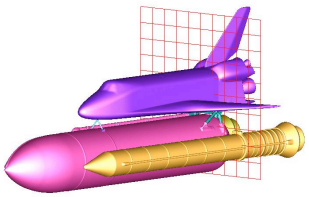
Initial positions and velocity directions display

Input parameters specification panel

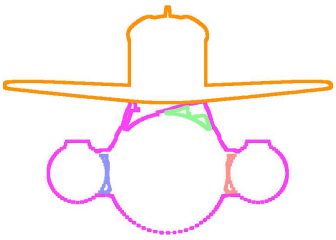
DISPLAY OF TRAJECTORIES, IMPACT POINTS AND SPEEDS IN OVERGRID'S DEBRIS INTERFACE

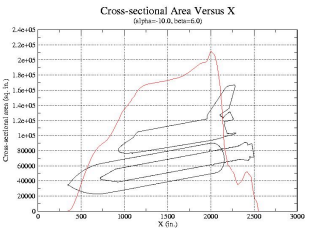


CAT SCAN UTILITY - TSCAN



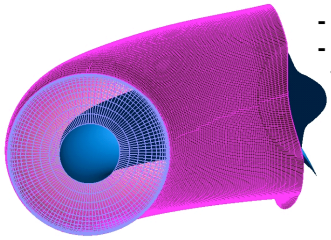
- Compute cross-sectional area versus X/Y/Z of a triangulated object at specified angle of attack and yaw
- Estimate wind tunnel blockage
- Proper treatment of non-simply-connected regions



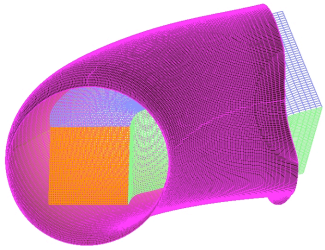


PIPE CORE GRID GENERATION TOOL - GENCORE

Automatic generation of singularity-free volume grids inside varying-diameter pipe



- avoids singular axis topology
- core automatically created from pipe shell



CGT SCRIPT LIBRARY DEVELOPMENT

> Macro Tcl procedures for grid generation script creation
> Factor of 10 or more compact scripts
> Factor of 3 or more faster in script development

Library procedures

- File manipulation (e.g., combine files, …)
- Grid information (e.g., interrogate dimensions, grid coordinates, arc lengths, …)
- Grid editing (e.g., extract, concatenate, split, duplicate, swap/reverse indices, translate, rotate, revolve, …)
- Grid redistribution
- Grid generation (e.g., TFI surface, hyperbolic and Cartesian volume, …)
- Math functions
- OVERFLOW namelist i/o
- Program execution and error checking

CGT SCRIPT LIBRARY EXAMPLES

```
set id [ open grided.i w ]
puts $id "in.dat"
puts $id "   1    1     ITIN,ITOUT"
puts $id "   1    MOP"
puts $id "   1    NGSO"
puts $id " 5"
puts $id "  11    IOP"
puts $id "   1   -1    1     JS,JE,JI"
puts $id "   1    1    1     KS,KE,KI"
puts $id "   1    1    1     LS,LE,LI"
puts $id "   0    IYN"
puts $id "   1    IYN"
puts $id "   1    MOP"
puts $id "   1    NGSO"
puts $id " 17"
puts $id "  11    IOP"
puts $id "   1   -1    1     JS,JE,JI"
puts $id "   1   -1    1     KS,KE,KI"
puts $id "   1    1    1     LS,LE,LI"
puts $id "   0    IYN"
puts $id "   1    IYN"
puts $id "   9    MOP"
puts $id "out.dat"
puts $id "   2    NWRITE"
puts $id " 5,  17"
puts $id "   0    IYN"
close $id
exec $File(GRIDED) < grided.i >& grided.o
```

Extract K=1 curve of grid 5 and entire grid 17 from file *in.dat* and write result to *out.dat*

```
ExtractSubs in.dat out.dat \
            [list 5 1 -1 1 1 1 1] [list 17]
```

Redistribute surface grid from file *in.sur* for all points in J direction with
- max stretching ratio of Sr
- end spacings of Ds1 and Ds2
- max spacing no larger than Dsmax
- number of points that will allow 3 levels of multi-grid

and write result to *out.sur*

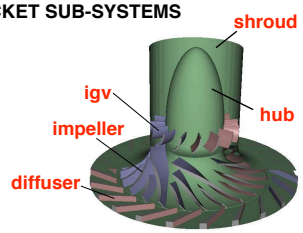
```
SrapRedist  in.sur  out.sur  1 J 1 5 3 \
            [list 1 -1 $Sr $Ds1 $Ds2 $Dsmax]
```


CGT SCRIPT LIBRARY APPLICATIONS

N-STAGE LIQUID ROCKET SUB-SYSTEMS

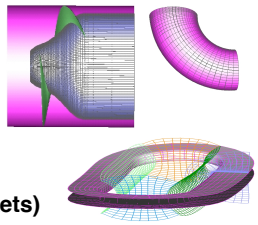
Objectives

Develop script system to automatically generate
- grids
- hole-cutting X-ray maps
- domain connectivity inputs
- flow solver inputs



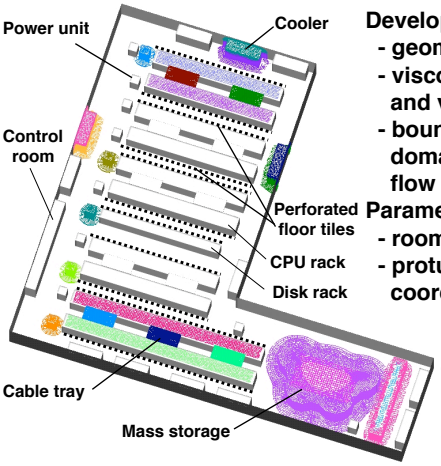
Capabilities

- component modules for
  - blade (inducer, inlet guide vanes, impeller, diffuser)
  - ring (hub to shroud section)
  - pipe (shroud only)
  - nose (hub end)
  - flowliner (bellows, valves, slots)
  - strut assembly (hub, vanes, brackets)



CGT SCRIPT LIBRARY APPLICATIONS

COMPUTER ROOM AIR FLOW SIMULATION



Developed script to create
- geometry
- viscous overset surface and volume grids
- boundary conditions, domain connectivity, and flow solver inputs

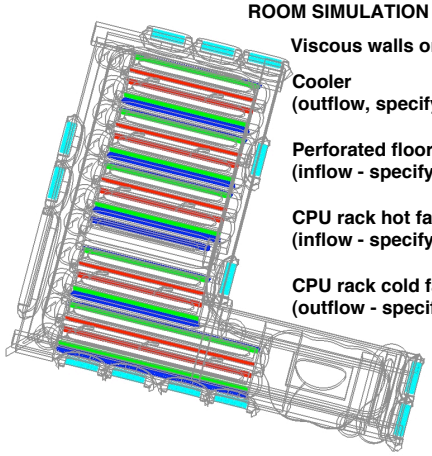
Parameterized inputs for
- room dimensions
- protuberance sizes and coordinates

Script created in about 3 man days

12 million points
102 grids

CGT SCRIPT LIBRARY APPLICATIONS

SCRIPT-GENERATED BOUNDARY CONDITIONS FOR COMPUTER ROOM SIMULATION



Viscous walls on all solid surfaces except

Cooler
(outflow, specify normal velocity)

Perforated floor tiles
(inflow - specify velocity and temperature)

CPU rack hot face
(inflow - specify velocity and temperature)

CPU rack cold face
(outflow - specify normal velocity)

SUMMARY

Tool suite (OVERGRID, OVERFLOW-2, OVERPLOT)

- developed for rapid, easy-to-use multi-body dynamics CFD simulations
- includes grid generation, input preparation, flow computation, dynamics animation, simple flow visualization, history plots of residuals, forces, moments, dynamics data, etc.

Expanded script library in CGT

- simplifies grid generation script creation
- more compact scripts
- less development time

FUTURE WORK

Over 100 items in CGT development to-do list

Short term - driven by Return-To-Flight and unsteady liquid rocket sub-systems simulations

Medium term - CAPRI interface for grid generation on native CAD models

Long term - hybrid overset grid technology